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# **STRYKER SUITABILITY STUDY**



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## **Executive Summary**

The cost of operating and maintaining weapon systems is a large expense to the Department of Defense. Suitability performance is a major factor affecting these costs. For many DoD acquisition programs, suitability lags effectiveness during program development. Suitability determinants (such as reliability and maintainability) are not addressed early enough and are not prioritized with the same vigor and discipline as performance parameters like speed, accuracy, and lethality. JROC, DOT&E, and USD(AT&L) have each called for increased attention to suitability improvement.

The primary purpose of this research study was to determine the operating and support costs of the Stryker family of vehicles and compare those costs to predicted and/or budgeted costs. The secondary purpose of this study was to investigate general suitability performance issues of this recently deployed system, which was accelerated into combat in 2003.

Researchers used field maintenance reports to gather support cost data for Stryker vehicles. Researchers then developed an independent methodology for estimating cost per mile values for CONUS and deployed vehicles. The methodology and assumptions resulted in cost estimates similar to other estimating techniques, demonstrating that this new methodology provides an independent verification of operating cost estimates. Data was not available from the government program office or the contractor to allow a direct comparison of operating costs estimates to predicted and/or budgeted support costs. The contract costs for labor and operational readiness cannot be broken down to enable a meaningful comparison.

Several suitability issues for the Stryker system were revealed during this study. Stryker is performing well in the field with an Operational Readiness Rate (ORR) consistently above the required contractual value. However, a harsh combat scenario, dynamic threat environment, and extremely high tempo of operations have created unique challenges to operators and maintainers.

## CHAPTER 1 – INTRODUCTION

### Background

In his first annual report to Congress the newly confirmed Director of Operational Test and Evaluation, Dr. Charles E. McQueary, made three initial observations. The first observation was that Operational Test & Evaluation (OT&E) is too often the place where performance deficiencies are discovered. It is important in the Department of Defense (DoD) acquisition process that problems are found early - either in government Developmental Test & Evaluation (DT&E) or contractor testing. Detecting and correcting design problems early in the development process will mitigate program cost overruns and schedule delays. The second observation was that the DoD acquisition system is inherently slow, and must improve to accommodate a more rapid fielding of new weapons systems and new technologies. The need for rapid fielding of new technology is evident in extended hostilities in Iraq and Afghanistan (e.g., armor for the High Mobility Multipurpose Wheeled Vehicle [HMMWV]). His third observation was that operational suitability of DoD systems is too low and needs to improve. Data for the previous three years (2004 through 2006) showed that 35% of Initial Operational Test & Evaluations (IOT&E) resulted in unfavorable suitability evaluations as reported to Congress in each system's Beyond Low Rate Initial Production (BLRIP) Report (Reference A).

While it is true that the technical performance of weapon systems (such as speed, accuracy, and firepower) has improved significantly over the last several decades, suitability parameters (such as reliability, availability, and maintainability) certainly have not. Figures 1, 2 and 3 clearly show that this problem has been a trend for more than 20 years. All data in Figures 1 through 3 are based on Army Test and Evaluation Command (ATEC) programs evaluated during the years shown. Figure 1 (Reference B) shows that from 1985 to 1990, only 41% of programs evaluated by ATEC successfully demonstrated reliability requirements during operational testing, while 59% did not. Figure 2 (Reference B) shows that between 1996 and 2000, only 20% of programs met reliability requirements, while 80% did



not. Figure 3 (Reference C) shows that from 1996 to 2005, only 34% of programs met reliability requirements, while 66% did not.

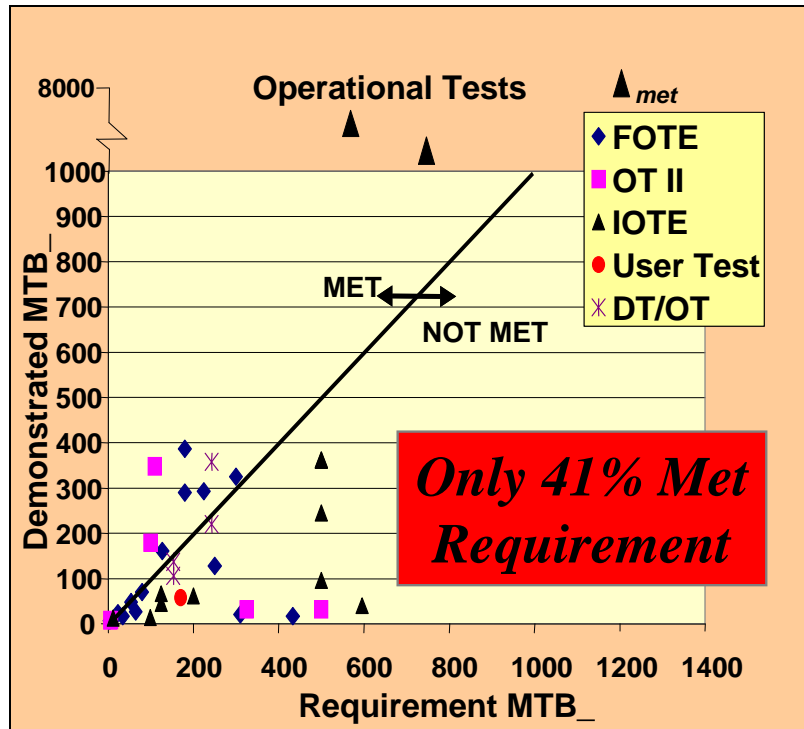


Figure 1 - Reliability During Operational Tests, 1985-1990

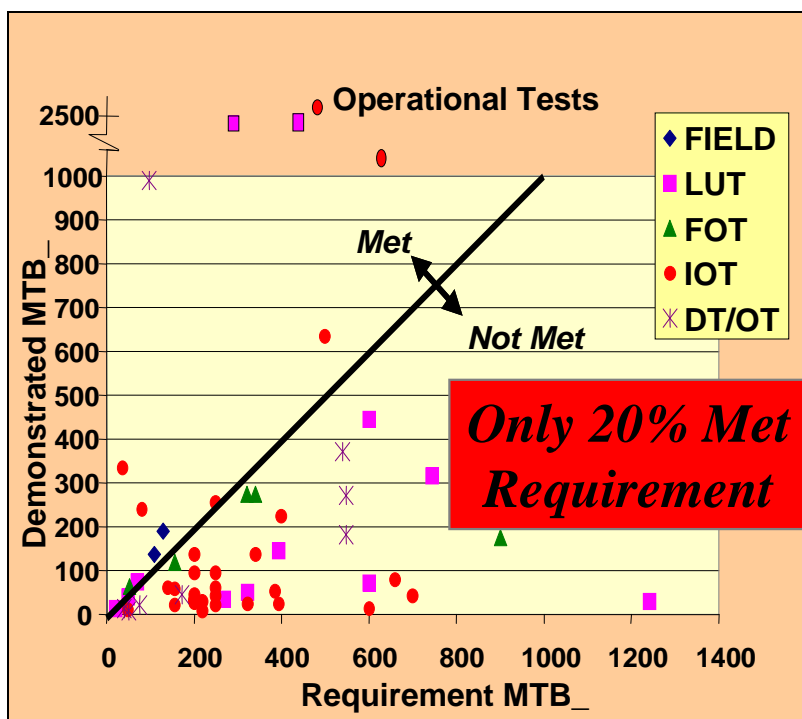


Figure 2 : Reliability During Operational Tests, 1996-2000

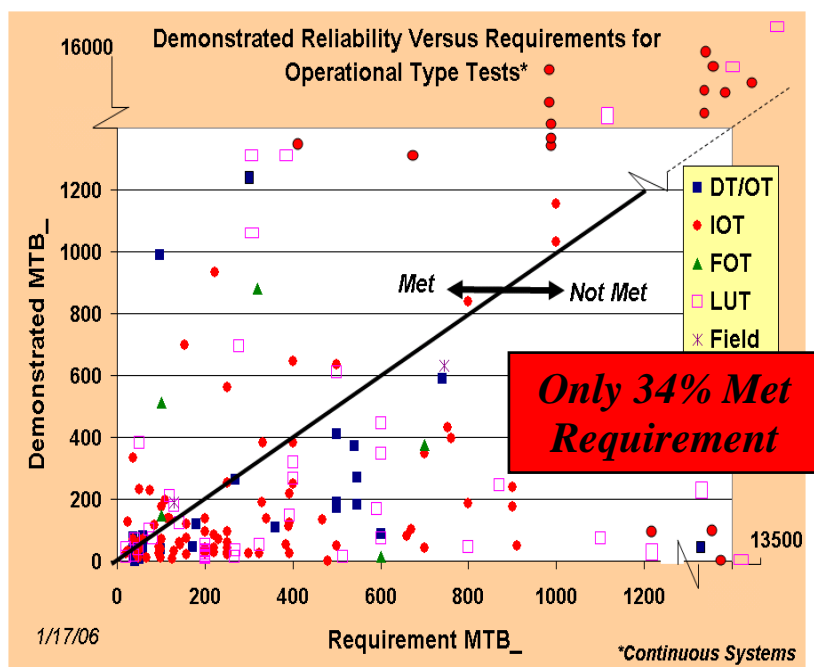


Figure 3 : Reliability During Operational Tests, 1996-2005

Stryker was a new Army program in 2000, but suitability issues were certainly not a new problem. The Defense Science Board (DSB) pointed out in 2000 that 80% of U.S. Army defense systems fail to achieve even half of their required reliability parameters (Reference D). Steps have been taken to help address this concern. In November 2004, the Undersecretary of Defense for Acquisition, Technology and Logistics (USD(AT&L)) directed that acquisition programs measure performance in terms of operational availability, mission reliability, and cost per unit of usage (Reference E). Three months later USD(AT&L) issued a memorandum on Total Life Cycle Systems Management (TLCSM) Metrics in which he provided specific definitions, formulas and metrics for calculating important suitability parameters, such as operational availability and mission reliability. In 2005, the DSB recommended that DoD aggressively pursue implementation of performance-based logistics for all weapon systems. The USD(AT&L) has also directed that the TLCSM Executive Council develop a metrics handbook to be used in performance-based contracts and sustainment oversight (Reference F). In August 2006, the Joint Requirements Oversight Council (JROC) mandated a Key Performance Parameter (KPP) of "Materiel Availability" including key system attributes of "Materiel Reliability" and "Ownership Costs" (Reference G). These initiatives were designed to improve operational performance, establish standard suitability metrics, and reduce life-cycle support costs of new DoD weapon systems.

Dr. McQueary's third observation in his FY-2006 Annual Report is the basis for this research study. Many times systems receiving favorable effectiveness evaluations but unfavorable suitability evaluations from IOT&E are fielded before suitability shortcomings are corrected. Even though there may be good reasons for deploying these systems (such as an urgent combat need or the negative consequences of stopping a production line), fielding systems before suitability deficiencies are corrected will result in reduced operational availability and increased support costs. Programs with suitability problems are likely to have low operational availability and high support costs. Low suitability directly results in increased life-cycle support costs. These costs can appear in many forms, such as: increased spares, increased contractor support, increased maintenance actions, increased

maintenance man-hours, decreased reliability, decreased availability, and decreased combat capability. Costs over and above the planned costs of life-cycle support can represent a large unbudgeted expense for DoD. This undesirable trend of low suitability during major weapon system development has been observed for at least 20 years, and this trend is not improving. The reliability success rate of systems tested in 1996-2005 (34%) is below the reliability success rate for 1985-1990 (41%).

In September 2006, the Office of DOT&E asked DAU to initiate a research study to examine the support costs of fielding systems that had not demonstrated desired levels of operational suitability in IOT&E. DAU proposed a two-phased approach. The first phase would be a pilot study to validate research methods and establish data availability on one selected program. Researchers would gather data on actual part failures and repair costs on a recently fielded program that had marginal suitability performance in IOT&E. Using the consumption and repair cost data, the researchers would then develop an independent methodology to estimate support costs. Researchers could then compare the estimated support costs to prior predictions and/or budgeted costs. The DOT&E office approved the first phase and selected the Stryker system for this research study.

In the second phase of the research project, a representative sample of various types of programs (two from each service) would be selected for follow-on studies. The objective would be the same as the pilot study – to compare actual support costs with systems demonstrating marginal suitability to predicted support costs. Suitability metrics, such as reliability, operational availability, and mean-time between failures, would also be compared to system requirements and specifications.

## **Research Study Objective**

The research study objective was to quantify the difference between projected O&S costs associated with the RAM requirement with the actual O&S costs associated with the achieved level of operational suitability.

**Research Question**

Research question: How do the Stryker System support costs compare to budgeted and/or planned support costs?

**Research Study Plan**

For this study, researchers planned to develop a basic understanding of the Stryker program through an intensive interview process and review of open literature as presented in Chapter 2. Two major themes were investigated during this research study:

**(1) Cost of Suitability:** Researchers planned to use actual field cost data to determine an independent estimate of support costs. The metric utilized was operating cost per mile (*cpm*). Researchers would then compare these support costs to pre-deployment predicted/budgeted costs from the Stryker program office.

**(2) General Suitability Performance:** In addition to operating costs, researchers planned to investigate various suitability performance issues on the Stryker system.

**Overview**

The Stryker family of vehicles was conceived as part of the Army's Transformation Campaign Plan. In 1999, General Eric Shinseki, the Army Chief of Staff, came to the conclusion that the Army had serious deployability and mobility issues (Reference H). Though the Army was capable of full spectrum dominance, its organization and force structure were not optimized for strategic responsiveness. Army light forces could deploy rapidly, but they lacked the lethality, mobility and staying power necessary to be effective in peacekeeping scenarios. On the other hand, Army mechanized forces possessed the necessary lethality and staying power, but they required too much time to deploy.

Subsequently, the Secretary of the Army announced a new Army vision in October 1999 to build a landpower force capable of strategic dominance across the

full spectrum of ground combat operations. The key to implementing this vision was for the Army to become more strategically responsive. Stryker was designed as a full spectrum, early-entry combat force and optimized primarily for employment in small scale contingencies. It was developed to operate in a complex environment, including urban terrain, while confronting low to mid-range threats with conventional and asymmetric capabilities. Requirements for the Stryker include rapid deployment, early entry execution, and to conduct effective combat operations immediately upon arrival (Reference I).

Stryker was initially deployed to Iraq in 2003 due to an urgent combat requirement. Stryker underwent an aggressive, accelerated development and test program. In order to field Stryker quickly, the complete spectrum of operational testing could not be performed within allowable time constraints. Therefore, Stryker was fielded without fully conducting operational tests on all potential missions and operating environments. In addition, a major configuration change was not included as part of IOT&E because add-on armor was not available (Reference J).

Schedule-driven compromises in IOT&E are not unusual to DoD programs. As noted in Reference D, page 19, *"Pressures on program officials to meet budgets and deadlines, due to congressional and other oversight, result in test strategies geared toward demonstrating "successful" performance. Thus, testing is often carried out under benign or typical stresses and operating conditions, rather than striving to determine failure modes and system limitations under more extreme circumstances."*

The Project on Government Oversight reported that Stryker was rushed through development, and lack of complete testing could give operators a false sense of security (Reference K). However, in the same newspaper article, the *Detroit News* acknowledged that reports from the field overwhelmingly indicated that Stryker was performing in an outstanding manner.

One of the early decisions made by the Army to support an accelerated development and deployment timeline was to rely on contractor performance based logistics (PBL) support within the Stryker brigades. Some of the duties of the

contractor personnel included conducting maintenance on the Stryker vehicle and managing the Stryker-specific supply chain. When Stryker was first deployed to Iraq, the Army did not have the institutional capability to train soldiers on conducting Stryker vehicle maintenance, and therefore faced an immediate need for contractor maintenance personnel to support the deployment (Reference L).

Each Stryker brigade was fielded with 45 imbedded vehicle maintenance contractor personnel. The Army desires to eventually replace the 45 contractors with active duty soldiers. Current plans call for implementation (removal of embedded contractors) to begin in 2008; however, the General Accountability Office (GAO) reported that this will be very difficult for the Army to achieve for several reasons. First, the 45 imbedded contractor maintenance personnel must be replaced by 71 soldiers due to other collateral duties and common training requirements of soldiers. Second, the Army is very short of personnel with the five military occupational specialties for wheeled vehicle mechanics, resulting in a very difficult recruiting challenge for the Army. Currently, as reported by the Washington Post (Reference M) and the New York Times (Reference N), the Army is indeed falling short of current recruiting goals.

## CHAPTER 2 - RESEARCH METHODS

### Literature Review

The research team first reviewed available open literature on the Stryker program. This included programmatic documents and reports from the Department of Army, the Department of Defense, and General Dynamics Land Systems (GDLS), the prime contractor. In addition, other unclassified documents, such as GAO reports and newspaper articles, were reviewed.

### Interviews

Interviews were conducted with representatives from the following organizations:

- Stryker Program Office Team, TACOM LCMC (Oct. 13, 2006, Jan. 17, 2007, June 19, 2007)
- USD(AT&L)<sup>1</sup> (Sept. 27, 2006, Dec. 19, 2006, Dec. 22, 2006)
- ATEC<sup>2</sup> (Dec. 6, 2006)
- AEC<sup>3</sup> (Dec. 6, 2006),
- OTC<sup>4</sup> (Dec. 8, 2006),
- IDA<sup>5</sup> (Dec. 20, 2006)
- LMI<sup>6</sup> (Dec. 20, 2006)
- GDLS<sup>7</sup> (Feb. 21-22, 2007)
- 3/2 Stryker Brigade Combat Team at Ft. Lewis, WA (Feb. 21-22, 2007)

### Data Analysis

One objective of the research study was to determine an independent operating cost per mile (*cpm*) for the Stryker combat vehicle. The *cpm* estimates reported in

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<sup>1</sup> Undersecretary of Defense for Acquisition, Technology and Logistics

<sup>2</sup> U.S. Army Test & Evaluation Command

<sup>3</sup> Army Evaluation Center

<sup>4</sup> Operational Test Command

<sup>5</sup> Institute for Defense Analysis

<sup>6</sup> Logistics Management Institute

<sup>7</sup> General Dynamics Land Systems



this report do not include battle damaged vehicle failures. Labor and part costs and vehicle miles are required in order to compute an operating cost per mile:

$$cpm = \frac{(TotalLabor) + (Total Consumed Parts)}{TotalVehicleMiles} \quad \text{Eq. 1}$$

It became obvious early in the research study that the OSMIS<sup>8</sup> database was lacking the detailed information required to estimate cost per mile. However, the contractor (General Dynamics Land Systems-GDLS) tracks vehicle repairable<sup>9</sup> and consumable parts, and repair labor hours. This data was provided to the program office per CDRLs in the contract. The CDRL data has been used to estimate the operating costs per mile for the Stryker variants. The two CDRL reports of interest are:

- CDRL A003 – Consumption Report
- CDRL A004 – Repairable Items Repair Cost Summary Report

Both reports were provided to the researchers by PM Stryker. The CDRL data was compiled by GDLS.

### **Total Labor Costs**

The vehicle maintenance labor is provided under a Performance Based Contract with GDLS. In garrison Mechanic direct labor is \$4.73M (FY05C\$) per brigade per year. The cost includes G&A, Fee and COM.

Labor to repair a damaged part is not explicitly included in the *cpm* equation but the costs are included in the Total Repair Price.

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<sup>8</sup> The Operating and Support Management Information System (OSMIS) is the core of the Army Visibility and Management of Operating and Support Costs (VAMOSOC) program. OSMIS tracks operating and support information for over one thousand major Army weapon/materiel systems for the Office of the Deputy Assistant Secretary of the Army for Cost and Economics. OSMIS-tracked systems include combat vehicles, tactical vehicles, artillery systems, aircraft, electronic systems, and miscellaneous engineering systems.

<sup>9</sup> The Army uses the word “reparable” while GDLS uses “repairable”.

**Part Costs**

When a part fails, the part can be scrapped or repaired. When the part is scrapped, it is replaced with a new part at standard cost. The scrap rate will be higher for inexpensive parts because the cost to repair an inexpensive may exceed the standard cost of the part.

For repaired parts, there may be a material charge (e.g. for damaged components) and a labor charge. The labor cost is included in the repair price of the part.

To determine the cost of consumable parts, four values are needed for each part: (1) the failure rate (parts per mile), (2) the standard cost, (3) the scrap rate, and (4) the average price of repaired parts.

CDRL A004 – Repairable Items Repair Cost Summary Report—was used to determine the last three values: standard cost, scrap rate, and the average price of repair.

The part failure rate (failures per mile) was determined from CDRL A003 – Consumption Report. The method for estimating the failure rate is complex and is presented in Chapter 4.

**Total Vehicles Miles**

Two data files contained mileage data for the 3/2 SBCT<sup>10</sup>. However, the mileage data was studied and it was determined that it was not reliable for the *cpm* analysis (see Appendix E).

Instead, CDRL A003 – Consumption Report—was used to determine the total vehicle miles. The analysis is presented in Chapter 4.

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<sup>10</sup> 3/2 SBCT : 3<sup>rd</sup> Brigade, 2<sup>nd</sup> Infantry Division, Stryker Brigade Combat Team

## CHAPTER 3 - FINDINGS

Researchers developed a basic understanding of the Stryker program through an intensive interview process, a review of open literature, and analysis of cost data. The following findings correspond to the two major themes of this research study:

### Theme 1 : Cost of Suitability

Researchers used actual field cost data to determine an independent estimate of support costs. The metric utilized was operating cost per mile (*cpm*).

#### Finding 1

An important metric in the Stryker program is *cpm*, which is used as a planning tool to project future budget requirements. Based on the data analysis used in this research report, the CONUS operational costs per mile for all variants and all vehicles were estimated at \$13.30/mile. The estimate was based on data from 747 CONUS vehicles with an average daily mileage of 7.3 miles. The DEPLOYED operational costs per mile for all variants and all vehicles were estimated at \$7.95/mile. The estimate was based on data from 656 DEPLOYED vehicles with an average daily mileage of 35.6 miles. DAU's independent *cpm* estimate and methodology is presented in detail in the next section of this report.

No specific value of *cpm* is required by contract. The government Stryker team and the contractor both calculate *cpm* independently and use results to negotiate spare parts costs forecasts and to determine purchasing requirements. For reference, several other *cpm* estimates from program literature are listed below:

- Reference X, (page 33) *cpm* estimate - \$ 18.23, based on M113A3 historical data (December 2005)
- Reference X, (page 34) *cpm* estimate - \$ 14.23, based on initial 4 months of deployment (December 2005)
- Reference U (page 15) *cpm* estimate for ICV - \$17.19 (August 2004)
- Reference Y (page 4) *cpm* estimate - \$18.78 (March 2004)

- GDLS *cpm* estimate - \$ 12.72 (March 2007)

## **Finding 2**

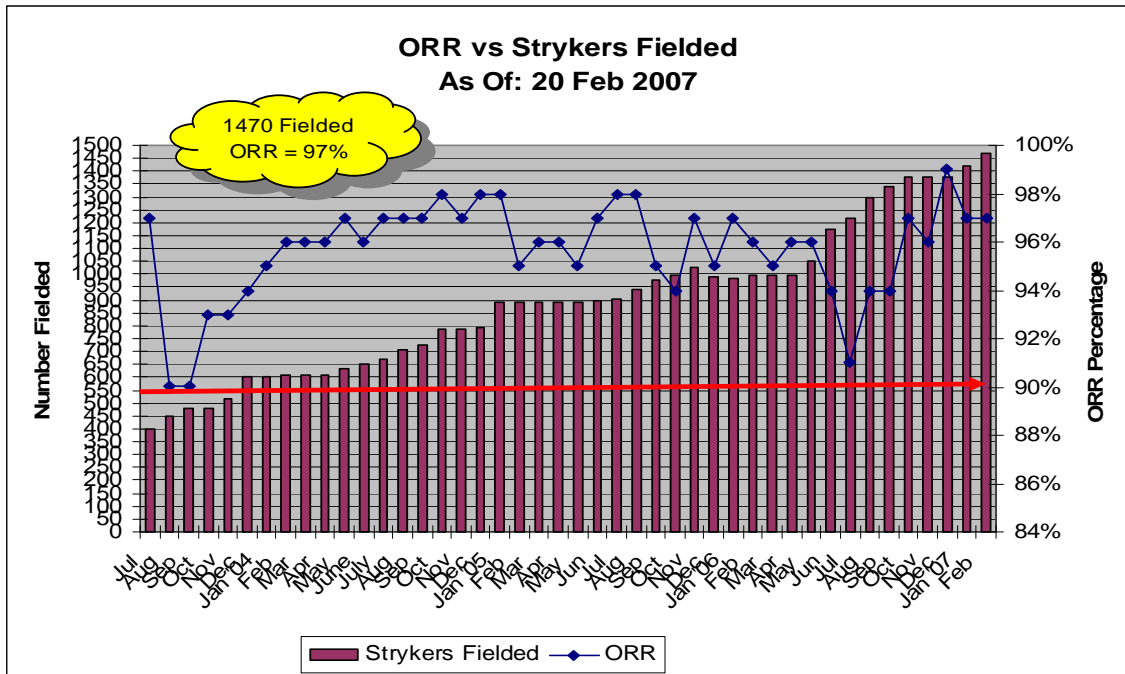
A key factor that might affect the Stryker cost per mile is operational tempo (OPTEMPO). The program office estimates that the operational tempo is 6 times the planned OPTEMPO. Other interviews yielded estimates of operational tempo up to 10 times the planned OPTEMPO. The St. Louis Post-Dispatch (Reference O) reports that vehicles in Iraq are using up 7 years of service life for each year of service in Iraq. The General Accountability Office (Reference L), estimates that service life is being expended 800% faster than expected. This greatly increased operational tempo may result in earlier failures than assumed in prior *cpm* estimates. Therefore, the *cpm* estimates derived in this research report may not be directly comparable to estimates from prior reports, which were based on much lower OPTEMPO rates. Additional research would be required to study the long-term impact of high OPTEMPO rates on support costs.

## **Theme 2 : General Suitability Performance**

In addition to operating costs, researchers planned to investigate various suitability performance issues on the Stryker system.

## **Finding 3**

A general finding of this study was that the Army is very satisfied with Stryker's performance in the field. System performance in an asymmetric combat scenario under difficult environmental conditions exceeds Army expectations. Brigade commanders have consistently reported high operational readiness rates (>90%) since Stryker was fielded, despite the fact that combat conditions in Iraq have been much different than expected. For example, from October 2003 to September 2005 the first two Stryker brigades deployed to Iraq reported an average Operational Readiness Rate (ORR) of 96% (Figure 4), well above the Army-established ORR performance goal of 90%.



**Figure 4 – Operational Readiness Rates**

Due to the asymmetric nature of the threat forces, and to the highly adaptive nature of the enemy, the combat scenarios and operating environment have been much different than expected. According to the Stryker Operational Mode Summary/Mission Profile (OMS/MP), the Stryker planned mission profile calls for operations on hard roads 20% of the time, and cross-country operations 80% of the time (Reference P). The actual Stryker usage in Iraq has been almost exactly the opposite (~80% on hard roads, 20% cross-country). Most missions resemble police actions in the urban environment on paved roads. Stryker crews must routinely drive over curbs and other small obstacles to navigate in the urban environment. This requires a higher tire pressure than normal causing more vibration and shock loads and high structural stress on the vehicles.

#### **Finding 4**

In response to the greater threat of rocket propelled grenades (RPGs), improvised explosive devices (IEDs) and small projectiles, the Army configured Stryker with an add-on slat armor package and crews added sand bags. The

increased the weight of the vehicle affected the performance of the Stryker family of vehicles in several ways.

(1) To operate with the increased vehicle weight, the operating tire pressure had to be increased from the design specification of 80 psi to 95 psi. Stryker is configured with a centralized tire pressure system that is designed to automatically keep the tire pressure at the optimum value for specific terrain conditions, speed, and traction. The automatic inflation system is not designed to maintain 95 psi, so soldiers must set tire pressure manually and check it three times daily (Reference Q). The requirement to over-inflate the tires to 95 psi and to physically check tire pressure three times per day is an operational nuisance because these are unplanned, but necessary, preventive maintenance actions. Additionally, the combination of routine excessive structural stress and increased tire pressure causes unanticipated structural failures. For example, a large number of wheel spindles developed fatigue cracks and had to be replaced early. Drive shafts are also failing sooner than expected.

(2) Due to the issues of added weight, excessive tire pressure, and severe operating conditions, tires are also failing at a high rate. In one 96-hour test period at Fort Erwin, CA with 16 Stryker vehicles, 13 tires had to be changed (Reference R). The Washington Post reported that 11 tire and wheel assemblies fail every day, and GAO (Reference S) asserts that each Stryker vehicle is going through one tire per day on average. The additional maintenance actions (checking/adjusting tire pressures and changing tires) are extremely burdensome to the crews since changing tires is not crew-level maintenance and requires special tools.

(3) The 5,000 pounds of armor to counter RPG threats is generally effective but has many negative operational consequences, such as limited maneuverability, increased component stresses, safety issues, and transportability issues.

The extra weight and increased physical dimensions caused by the add-on slat armor adversely impacts performance, especially when maneuvering in spaces with narrow clearance and maneuvering in wet conditions.

Operations in soft sand or wet conditions (mud) place additional stress on engines, drive shafts, and differentials and these items have experienced higher than normal failure rates (Reference T).

Also, the slat armor causes multiple problems for safe and effective operations. Slat armor can deform during normal operations, sometimes blocking escape hatches and the rear troop egress door. The armor adds approximately 3 feet to the vehicle's width and can interfere with the driver's vision. Armor also makes it difficult for others to see the Stryker at night, which is a safety hazard in the urban environment. The armor is very heavy for the rear ramp and strains lifting equipment, requiring crews to sometimes manually assist raising or lowering the rear ramp. The armor attaching bolts on the rear ramp can break off with normal use, and may generate an unsafe condition and will increase maintenance burden. In addition, slat armor prohibits normal use of storage racks, which may impact operations. Lastly, slat armor affects the transportability of the vehicle in a C-130, since the extra weight greatly reduces transport range (Reference U).

Even though these operational issues caused by the add-on slat armor place additional maintenance burdens on crews, Stryker has been reported to be well-suited for the urban fight. Unlike the M-1 tank, Stryker can operate very quietly at high speed, which can be a tremendous tactical advantage (Reference V). Most Army personnel interviewed felt strongly that Stryker's tactical performance in the urban environment in Iraq is significantly better than the M113A3, HMMWV, Bradley Fighting Vehicle, or Abrahms Tank.

## **Finding 5**

In response to unanticipated urgent combat needs in Iraq, some engineering improvements were performed on the Stryker. Since the Army did not buy the technical data package because of its cost, these engineering changes have resulted in increased costs and potential risks (Reference W). GAO reports that current DoD acquisition policies do not specifically address long-term technical data rights for weapon system sustainment. As part of the department's acquisition

reforms and performance-based strategies, DoD has de-emphasized the acquisition of technical data rights. Although GAO has recommended that DoD recognize the need for the acquisition of technical data rights, DoD has not implemented these recommendations. GAO asserts that without technical data rights, DoD may face challenges in efficiently sustaining weapon systems throughout their life cycle.

### **Finding 6**

A very important contractual requirement for the prime contractor, General Dynamics Land Systems (GDLS), is to maintain an Operational Readiness Rate (ORR) of 90% or better. This requirement pertains only to the base vehicle configuration and does not include GFE. Since initial deployment, Stryker has routinely exceeded this requirement. The Cost Plus Fixed Fee (CPFF) contract effectively motivates GDLS to exceed 90% ORR; however, the contract is not necessarily effective at controlling support costs, and this may be a risk to the government (Reference X). One example of this is the repair and replacement of a high failure item, for example, cracked hydraulic reservoirs in the power pack. Maintenance procedures call for the entire power pack to be replaced as a unit, rather than removing and repairing/replacing the hydraulic reservoir within the power pack. This procedure produces shorter down-times (resulting in higher ORR) but it also requires more power packs (very large, expensive units) to be purchased and shipped to operating bases and maintenance facilities.

### **Finding 7**

Since Stryker's initial deployment was accelerated to meet an urgent combat need, the Stryker program team was performing several activities concurrently: testing, production, fielding, training and combat. In addition to the many challenges caused by these concurrent activities, the threat and operational environment in Iraq were different than anticipated, as previously mentioned. Several other factors added to the difficulty of maintaining Stryker vehicles in the field.

First, the Interactive Electronic Technical Manuals (IETMs) were not mature at the time of initial fielding. Many maintenance procedures could not be performed



based on the IETMs because they were either not characterized correctly or crews were not adequately trained on how to use them. This situation led to “tribal system maintenance”, where units depended on soldiers with experience on similar systems (like the M-113 armored personnel carrier) to figure out how to make the maintenance actions work successfully.

Second, since a large portion of maintenance actions were supported by contractor personnel, soldiers developed a “rental car mentality”. This lack of “ownership mentality” resulted in soldiers being overly dependent on contractor personnel to perform routine preventive maintenance actions, such as checking fluid levels. One vehicle was lost because the pre-mission engine oil check was ignored.

## CHAPTER 4 – METHODOLOGY

### Definitions

Vehicle operating costs include the cost for preventive maintenance, repair, and the cost of consumable and reparable parts. The Army calculates vehicle cost per mile by tracking vehicle mileage and the actual costs of consumable<sup>11</sup> or reparable<sup>12</sup> parts used<sup>13</sup> (Reference U).

### Available Data

The reports used in the estimation of *cpm* are:

- CDRL A003 – Consumption Report
- CDRL A004 – Repairable Items Repair Cost Summary Report

All reports were provided by PM Stryker. The CDRL data originated from GDLS. Two vehicle mileage reports provided by the PM were evaluated but not used in the *cpm* calculation (see Appendix E).

### Method for Estimating the Operating Cost Per Mile

The Army calculates vehicle cost per mile by tracking vehicle mileage and the actual costs of consumable or replaceable parts used.

The cost-per-mile equation can be written as

$$cpm = \frac{(TotalLabor) + (Total Consumed Parts)}{TotalVehicleMiles} \quad \text{Eq. 2}$$

The Total Labor costs are known from the contract. The Total Parts consumed are listed in A003, although the repair costs are more accurately reflected in A004. The remaining quantity (Total Vehicle Miles) is not known.

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<sup>11</sup> The Army's spare parts include reparable and consumable parts. Consumable parts are used to fix reparable parts and vehicles. For example, for example nuts, bearings, and tires are consumable parts.

<sup>12</sup> Repairable parts are expensive items, such as hydraulic pumps, navigational computers, and powerpacks, which can be repaired and used again.

<sup>13</sup> Operating costs do not include petroleum, oil and lubricant costs.

Because there are a large number of Stryker vehicles in a brigade, it is reasonable to calculate the cost per mile as

$$cpm \cong \frac{(Total\ Labor\ for\ a\ Brigade\ in\ a\ Year)/365}{(Total\ Vehicles\ in\ a\ Brigade) * (AvgVehicleMiles\ per\ Day)} + \frac{(Total\ Consumed\ Parts)}{TotalVehicleMiles} \quad \text{Eq. 3}$$

There are still unknowns in the above equation: namely the *average vehicle miles per day* and the *total vehicle miles*. The approach is simple in concept but difficult in implementation. When A003 contains two or more part failures on the same vehicle, an estimate of the vehicles consumed parts per mile can be determined. CDRL A003 lists each part consumed by variant type and vehicle number. It also lists the date and vehicle mileage on the vehicle when the part was consumed.

The vehicle mileage and date can be used to determine a vehicle's average miles per day:

$$miles\ per\ day\ for\ vehicle\ j = \frac{(Latest\ Mileage\ Vehicle\ j) - (Earliest\ Mileage\ Vehicle\ j)}{(Latest\ Date\ Vehicle\ j) - (Earliest\ Date\ Vehicle\ j)} \quad \text{Eq. 4}$$

The average miles per day can also be computed for each variant type (data is collected only for vehicles of each variant type):

$$avg\ miles\ per\ day = \frac{\sum_j (Latest\ Mileage\ Vehicle\ j) - (Earliest\ Mileage\ Vehicle\ j)}{\sum_j (Latest\ Date\ Vehicle\ j) - (Earliest\ Date\ Vehicle\ j)} \quad \text{Eq. 5}$$

The *avg miles per day* data, when combined with the daily direct labor and the number of Stryker vehicles in a Brigade, yields the direct labor per mile. (When computing a variant's direct labor cost/mile, the total direct labor is prorated by the percentage of each variant type in a brigade).

### Consumable Operating Cost Per Mile

The second term in Eq. 3, namely

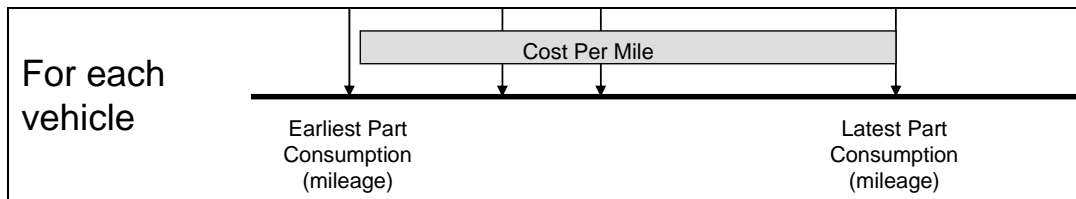
$$\text{consumable cost / mile} = \frac{\text{Total Consumed Parts}}{\text{Total Vehicle Miles}} \quad \text{Eq. 6}$$

cannot be determined from the data. Even though the total cost of parts (including repair costs) can be determined from CDRLs A003 and A004, the total vehicle mileage is unknown.

The CDRL A003 data is used in another way to compute the consumable cost/mile. Specifically, for a vehicle with 2 or more failures, an approximate value for consumable cost per mile for vehicle  $j$  is given by:

$$\text{consumable cost per mile}_j \approx \frac{\sum_{i=2}^n \text{Cost of Part}_{j,i}}{\text{Mileage}_{j,n} - \text{Mileage}_{j,1}} \quad \text{Eq. 7}$$

where  $n$  is the total number of consumed parts for vehicle  $j$ ,  $\text{mileage}_{j,n}$  is the mileage reading for the last part replaced, and  $\text{mileage}_1$  is the mileage reading for the first part replaced. Graphically, Eq. 7 is shown in Figure 5.



**Figure 5 – Estimating Consumable Cost Per Mile from A003**

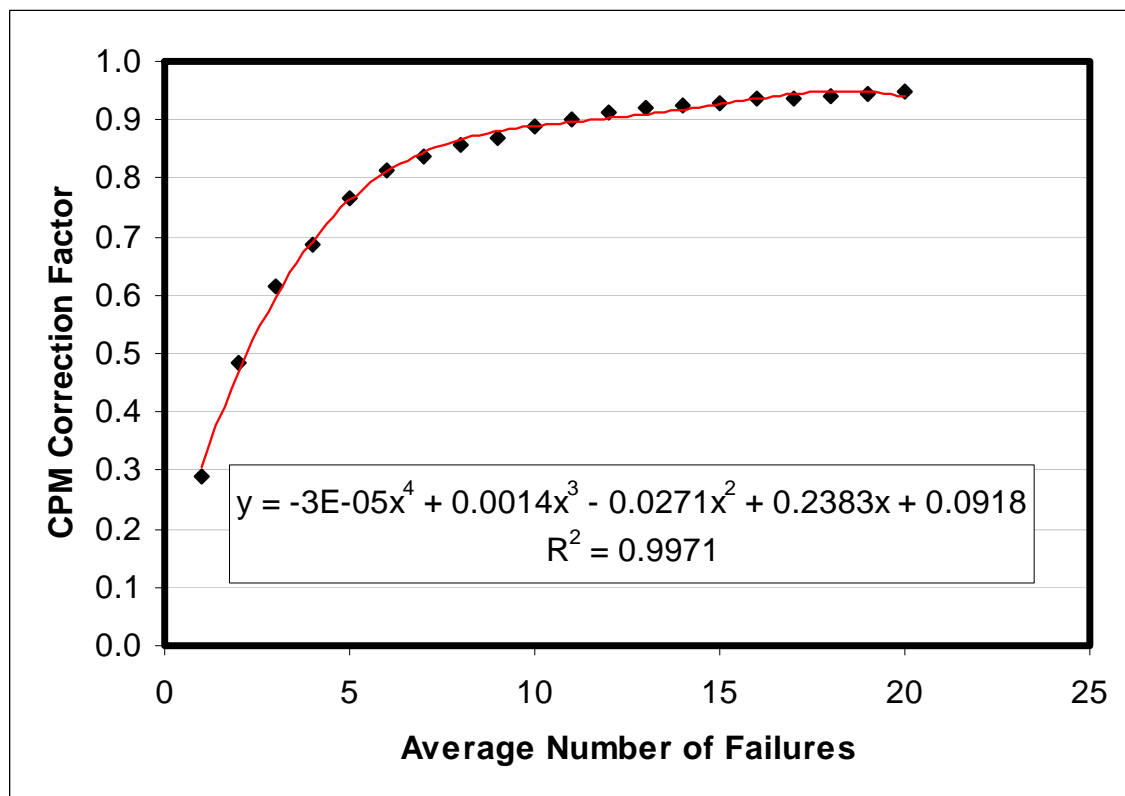
An Monte Carlo<sup>14</sup> analysis of the method shows that for a small number of failures, Eq. 7 over-estimates the cost/mile. This error can be observed in Figure 5. The mileage from the last reported failure to the end of the reporting period is not

<sup>14</sup> The Monte Carlo technique is a widely used class of computational algorithms for simulating the behavior of various physical and mathematical systems. They are distinguished from other simulation methods by being stochastic, that is, by randomly sampling events based on probability density functions to simulate each event in a physical process.

included in the cost/mile computation. Thus, a vehicle's cost/mile is over-estimated.<sup>15</sup>

### Correction to Estimated Consumable Cost per Mile

To correct for the error introduced by Eq. 7, a factor is applied to correct for the mileage not included in the equation. A Monte Carlo program was written to develop the correction factor based on the number of failures. For a given failure rate, the Monte Carlo program randomly sampled the mileage to the next failure. The correction factor was determined from the Monte Carlo results by taking the total repair cost for a given interval divided by the repair cost that would have been calculated from Eq. 7 (see also Figure 5). The results from the Monte Carlo simulation, shown in Figure 6, show that there is a large correction factor when there are only a few reported failures (e.g., a 50% correction when 2 failures are reported).



**Figure 6 – Correction Factor**

<sup>15</sup> It is ironic that the more reliable systems result in larger errors in the estimated consumable cost/mile.

## Data from CDRLs A003 & A004

### Labor Costs

GDLS and the PMO provided the following data:

- Vehicle mechanic direct labor: \$4.73M per brigade (average for CONUS and deployed)
- ~300 Stryker vehicles per brigade

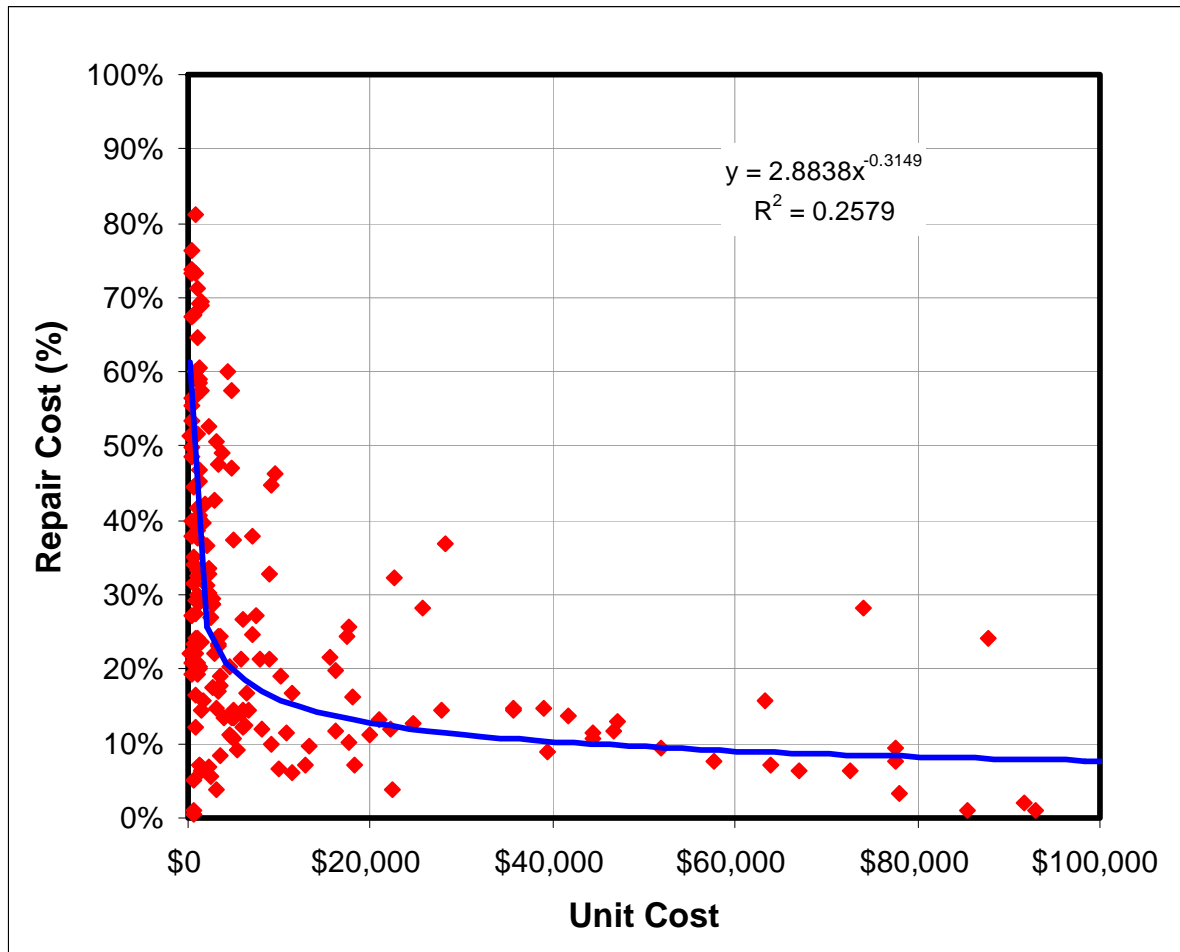
### Repair Cost Estimates from CDRL A004

While the A003 Consumption Report lists the parts replaced on the vehicles, the stated repair costs are inaccurate and incomplete. The A004 Repairable Items Repair Cost Summary Report has better estimated repair costs.

A Visual Basic software program was written to analyze the CDRL A004 data to compute an average repair cost for the parts listed. However, the CDRL A004 report only includes 26% of all the parts consumed. To overcome the lack of data (due to the limited operational history of the Stryker family of vehicles), a parametric model was created to estimate repair costs as a function of standard (or unit) cost. For example, the repair costs as a percentage of unit cost are expected to decrease as the unit cost increases (e.g., the repair of a PowerPack may be a few thousand dollars rather than the replacement cost).

The repair cost data (as a function of unit cost) and the repair cost parametric model are shown in Figure 7. The red points show the average repair costs, while the solid blue line is a power function regression of the data. However, because of the high value of the PowerPack, the repair cost of the PowerPack was left as a variable in the cost-per-mile model. For the base case it was assumed to be 30% of the unit cost.

The average repair cost from CDRL A004 was found to be 33%. This value was also used in the *cpm* analysis to determine if an average repair cost, rather than individual repair costs, could be used to predict the cost per mile.



**Figure 7 – Repair Cost Data**

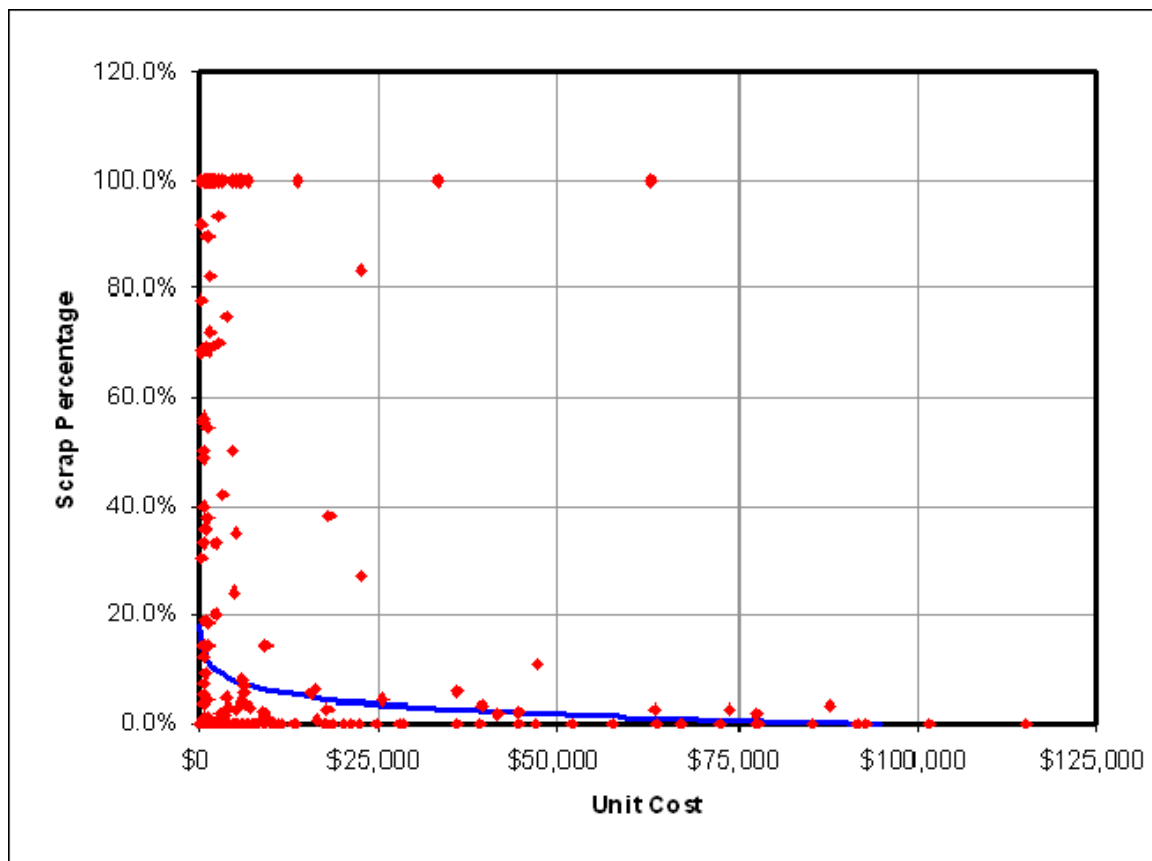
### **Scrap Rate from CDRL A004**

For each part listed in CDRL A004, there is a field indicating whether the part was repaired or replaced. A Visual Basic software program was written to analyze the CDRL data, and to compute an average scrap rate for the parts listed, and to record the scrap rate as a function of the standard cost of the part.

However, the CDRL A004 report only includes 26% of all the parts consumed. To overcome the shortage of data (due to the limited operational history of the Stryker family of vehicles), a parametric model was created to estimate scrap rates as a function of standard (or unit) cost. For example, a low dollar part will usually be

scrapped and replaced with a new part. A high dollar item will usually be repaired rather than scrapped. So it is logical to expect a relationship between unit cost and the scrap rate.

The scrap rate data and parametric model are shown in Figure 8. In many cases, the scrap rate was based on a sample size of one. Therefore, parts with a high unit cost and a high scrap rate were not used in the determination of the regression function. The data shows the incomplete nature of the database.



**Figure 8 – Scrap Rate Data & Parametric Model**

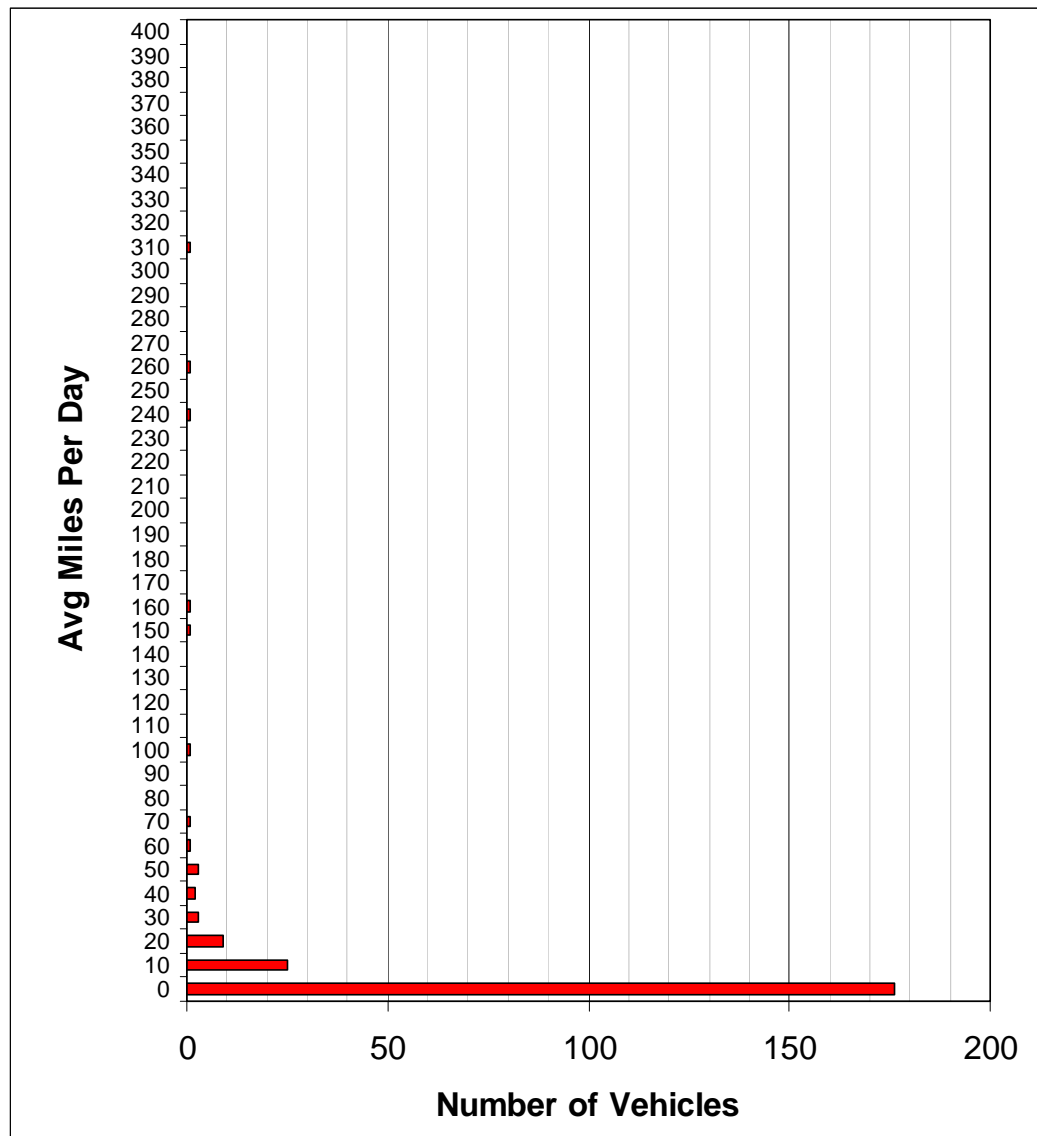
### **Mileage Data from CDRL A003**

While A003 is a parts consumption report, it contains the date and mileage of vehicles needing parts. The data has been used to estimate the miles/day for each



vehicle, for variant type, and for all vehicles using Eq. 4. Figure 9 is a histogram showing the number of vehicles that have miles/day between 0 and 10, 11 and 20, and so forth. The data shows that 90% of the vehicles analyzed had a maximum of 20 miles/day and 97% had a maximum of 80 miles/day. There are some vehicles that had unrealistic mileage rates (e.g., 310 miles/day). While it is possible to operate the vehicle for 310 miles in a day, it is unlikely that it was used for 9300 miles in one month. A more likely explanation is that the vehicle had only 2 failures during the reporting interval, and the failures occurred in a relatively short span of time.

Nevertheless, the mileage data shows that it is reasonable to limit the vehicle data used in the *cpm* analysis to vehicles with fewer than 50 miles/day (or even 100 miles/day). This discrimination is important to prevent data outliers from biasing the average values computed from the data.



**Figure 9 – Vehicle Miles/Day Based on A003**

## Implementation

There were several implementation issues for the *cpm* analysis. First, repair cost data from CDRL A004 had to be combined with the CDRL A003 consumable data. Second, data was listed by vehicle number and type. Therefore, CDRL A003 had to first be analyzed to determine the vehicles listed in the report. Then, consumable data for each vehicle had to be collected from the report. Third, data had to be accumulated for each variant. Fourth, *cpm* estimates had to be generated for

**CONUS** separately from **deployed**. Fifth, the scrap rates and repair cost models had to be implemented in the *cpm* estimates. Finally, data screening was performed to eliminate data outliers.

Several Visual Basic programs were developed to process the CDRL A003 and A004 data and to develop the *cpm* estimates for each variant type.

An overall top-level description of the analysis for CONUS and Deployed is listed below.

1. Process CDRL A004 to determine the repair costs for every part number with a repair cost listed in the report.
2. Analyze the CDRL A004 data to develop a parametric model of repair costs vs. unit cost to estimate repair costs of parts contained in CDRL A003 but not listed in CDRL A004.
3. Process CDRL A004 to determine the scrap rates for every part number listed in the report.
4. Analyze the CDRL A004 data to develop a parametric model of scrap rates vs. unit cost to use to estimate the scrap rate of parts contained in CDRL A003 but not listed in CDRL A004.
5. Scan CDRL A003 to identify all of the vehicles listed in the report.
6. Analyze CDRL A003 for each vehicle, recording all consumed parts, the vehicle mileage and the reported date of the request.
7. For the data collected for each vehicle:
  - a. For each part, apply a known scrap rate if available, otherwise apply the parametric model to estimate the scrap rate based on standard cost.
  - b. If the part will be repaired, apply the average repair cost from CDRL A004 if available, otherwise apply the parametric model to estimate the repair cost based on the standard cost.
  - c. From CDRL A003, use the minimum and maximum mileages to compute the total mileage for each vehicle.
  - d. From CDRL A003, use the total costs and minimum and maximum mileages to compute a cost per mile for each vehicle.
  - e. From CDRL A003, use the minimum and maximum mileages and the minimum and maximum dates to compute an average miles/day for each vehicle.
8. Collect data for each variant. Prorate direct mechanic labor by variant type (based on total mileage for each variant). Accumulate total miles and

total part replacement costs (repair plus scrap). Compute *cpm* for each variant.

9. Repeat above step for all variant types.

## CONUS Cost-Per-Mile Estimates

### Assumptions for the CONUS Estimates

The following assumptions were made in the CONUS cost-per-mile calculations:

- \$4.73M labor cost per brigade.
- CDRL A003 contains all consumable parts.
- CDL A004 contains relevant repair costs (especially items identified as a quote or an invoice).
- The scrap rate parametric model as shown in Figure 8 is valid (used for parts that do not have a known scrap rate).
- The repair cost parametric model as shown in Figure 7 is valid (used for parts that do not have any historical repair cost data).
- Replacement cost per mile determined from A003 and the first and last mileage readings.
- Corrections based on Figure 6.
- Repair cost of the PowerPack was assumed to be 30% of the standard cost.
- No reduction in replacement costs for items under warranty, since a warranty only affects initial repair costs.
- Only vehicles with more than 10 miles in the reporting period were used in the *cpm* analysis (others were assumed to have erroneous mileage readings)
- Only vehicles with less than 5000 miles in the reporting period were used in the *cpm* analysis (others were assumed to have erroneous mileage readings)
- Only vehicles with less than an average of 100 miles/day in the reporting period were used in the *cpm* analysis.
- 300 Stryker vehicles per brigade.

## CONUS COST-PER-MILE Estimates

The operational costs per mile for 7 variants (data did not exist for the other 3 variants) and for all of the Stryker vehicles are listed in Table 1. As a fleet, a *cpm* estimate of \$13.30/mile was based on data from 747 vehicles. Average daily mileage was 7.3 miles.

**Table 1 – Estimated Stryker Cost/Mile, CONUS**

Vehicle Type	No. Vehicles	Repair Cost in Computation	Total Mileage in Computation	Spares/ Repair Parts Cost/mile	Miles Per Day	Total CPM
ICV	345	\$1,581,641	218,138	\$7.25	7.56	\$9.41
MCV	101	\$279,921	22,504	\$12.44	5.39	\$14.59
ATGM	43	\$172,499	20,200	\$8.54	6.67	\$10.69
ESV	29	\$395,797	28,970	\$13.66	9.51	\$15.82
FSV	33	\$165,540	18,558	\$8.92	6.90	\$11.08
MEV	35	\$66,682	17,405	\$3.83	6.16	\$5.99
RV	161	\$559,520	110,313	\$5.07	7.32	\$7.23
<b>All vehicles</b>	<b>747</b>	<b>\$3,221,599</b>	<b>436,088</b>	<b>\$7.39</b>	7.31	\$13.30

## Deployed Cost-Per-Mile Estimates

### Assumptions for the Deployed Estimates

The following assumptions were made in the Deployed cost-per-mile calculations:

- \$4.73M labor cost per brigade.
- CDRL A003 contains all consumable parts.
- CDL A004 contains relevant repair costs (especially items identified as a quote or an invoice).
- The scrap rate parametric model as shown in Figure 8 is valid (used for parts that do not have a known scrap rate).
- The repair cost parametric model as shown in Figure 7 is valid (used for parts that do not have any historical repair cost data).
- Replacement cost per mile determined from A003 and the first and last mileage readings.

- Corrections based on Figure 6.
- Repair cost of the PowerPack assumed to be 30% of the standard cost.
- No reduction in replacement costs for items under warranty, since a warranty only affects initial repair costs.
- Only vehicles with more than 10 miles in the reporting period were used in the *cpm* analysis (others were assumed to have erroneous mileage readings)
- Only vehicles with less than 20,000 miles in the reporting period were used in the *cpm* analysis (others were assumed to have erroneous mileage readings) *[this was a different assumption than for CONUS]*.
- Only vehicles with less than an average of 400 miles/day in the reporting period were used in the *cpm* analysis *[this was a different assumption than for CONUS]*.
- 300 Stryker vehicles per brigade.

### Deployed COST-PER-MILE Estimates

The operational costs per mile for the 7 variants and for all vehicles are listed in Table 2. As a fleet, a *cpm* estimate of \$7.95/mile was based on data from 656 vehicles. Average daily mileage was 35.6 miles.

**Table 2 – Estimated Stryker Cost/Mile, Deployed**

Vehicle Type	No. Vehicles	Repair Cost in Computation	Total Mileage in Computation	Spares/ Repair Parts Cost/mile	Miles Per Day	Total CPM
ICV	315	\$8,225,102	1,108,756	\$7.42	36.93	\$9.57
MCV	70	\$765,983	120,708	\$6.35	22.08	\$8.50
ATGM	52	\$1,393,062	218,260	\$6.38	43.50	\$8.54
ESV	28	\$587,658	134,119	\$4.38	64.33	\$6.54
FSV	27	\$486,028	95,890	\$5.07	36.94	\$7.22
MEV	38	\$223,414	79,945	\$2.79	25.70	\$4.95
RV	126	\$2,303,741	317,632	\$7.25	31.72	\$9.41
<b>All vehicles</b>	<b>656</b>	<b>\$13,984,989</b>	<b>2,075,310</b>	<b>\$6.74</b>	35.59	\$7.95

**Deployed vs. CONUS Costs-Per-Mile**

There are several observations about the CONUS and Deployed *cpm* estimates. First, the data shows that the usage of deployed vehicles is about 5 times that of CONUS vehicles. This is consistent with some of the OPTEMPO estimates listed in Chapter 3.

The CONUS cost-per-mile estimate is higher than the deployed estimate. This is counter intuitive. Possible factors contributing this observation include:

- Incorrect assumption that the labor cost for Deployed is \$4.73M per brigade.
- More knowledgeable operators in the Area of Responsibility (AOR) while CONUS vehicles are often used for training of new operators.
- Early “bath-tub” failures that are detected before the vehicle has been deployed.
- Unreported failures in AOR (e.g., failures that do not significantly impact the mission).
- Unreported repairs in AOR (e.g., by a soldier in the field).

**Sensitivity Study**

A sensitivity study was performed to determine the sensitivity of the assumptions used in the calculations.

- Using an average repair cost rather than individual repair costs and the parametric model only drops the cost-per-mile values by 2%. This finding shows that less sophisticated cost models based on an average repair cost would produce similar results.
- Increasing the limit on miles/day from 100 to 300 (CONUS data) only drops the cost per mile by 3%. Therefore, the assumption on miles/day to eliminate suspect data does not strongly affect the results.
- Increasing the limit on total miles from 5,000 to 10,000 miles (CONUS data) only drops the cost per mile by 4%. Therefore, the assumption on total miles to eliminate suspect data does not strongly affect the results.

## CHAPTER 5 – CONCLUSIONS & RECOMMENDATIONS

### Conclusions

The following conclusions correspond to the two major themes (Cost of Suitability and General Suitability Performance) of this research study:

#### Theme 1 : Cost of Suitability

Researchers used actual field cost data to determine an independent estimate of support costs.

1. Cost-Per-Mile estimates based on field data for the Stryker vehicles (CONUS and DEPLOYED) were based on independent assumptions and methodologies. Based on the data analysis used in this research report, the average CONUS operational cost per mile for all vehicles was estimated at \$13.30/mile. The DEPLOYED operational cost per mile for all vehicles was estimated at \$7.95/mile.
2. The new methodology for estimating cost per mile based on data typically available for major weapons systems was proven to give values close to other estimation techniques. This comparison demonstrates that the new cost estimating methodology provides an independent verification of operating costs.
3. The research study objective was to quantify the difference between projected support costs with actual support costs associated with the achieved level of operational suitability. Data was not available to allow a direct comparison for several reasons.
  - Harsher combat environment.
  - Higher OPTEMPO than originally forecasted.
  - A dynamic product baseline (i.e., design changes).
  - Contract type and reporting requirements. The focus on one top-level metric (ORR) masked the achieved levels of suitability for lower level components.



## **Theme 2 : General Suitability Performance**

In addition to operating costs, researchers investigated various suitability performance issues on the Stryker system.

1. Stryker is performing very well in the field. The system is exceeding expectations of Army management, as well as soldiers in the field. In spite of a changing threat environment (improved IEDs and excessive operations in the urban environment) and major configuration changes (5000 pounds of add-on armor), Stryker is accomplishing its mission. The Operational Readiness Rate has consistently been over 90%.
2. Due to the increased threat of RPGs and IEDs, Stryker was outfitted with an add-on armor package. The additional 5000 pounds of armor has been generally effective at mitigating the threat, but results in some negative operational consequences. The extra weight requires increased tire pressure, which causes operational problems and more structural stresses. Additionally, the armor limits crew visibility during operations and restricts airlift transportability on a C-130 aircraft.
3. Army decisions regarding contractor logistics support will remain with the Stryker program for years. When Stryker was first deployed to Iraq in 2003, the Army faced an immediate need for contractor maintenance personnel to support operations (45 vehicle maintenance personnel per brigade). The Army plans to replace the contractors with soldiers, but it will take approximately 71 soldiers per brigade to perform the same level of vehicle maintenance. The current plan is to begin the transition to soldier maintenance in 2008, but the transition will be difficult due to the poor recruiting/retention outlook in general, and to the shortage of appropriate active-duty maintenance personnel.
4. Stryker program development was accelerated to meet the Army's combat needs in Operation Iraqi Freedom. Due to the compressed developmental schedule, Stryker DT/OT was unable to fully test all configuration changes.

DT revealed relevant problem areas, but there was insufficient time or priority to correct all problems before OT and fielding.

5. For many DoD acquisition programs, the maturity of suitability parameters lags the maturity of effectiveness parameters during program development. Suitability determinants (such as reliability and maintainability) are not addressed early enough and are not prioritized with the same vigor and discipline as performance parameters like speed, accuracy, and lethality.
6. The general issue of suitability shortfalls in DoD acquisition programs are recognized at high levels of management and are being addressed. JROC, DOT&E, and USD(AT&L) have each called for increased attention to suitability improvements. For example, a new requirement exists for a Materiel Availability KPP.
7. The operational tempo of Stryker vehicles in Iraq far exceeds original usage estimates by at least 500%. Also, the mission profile of Stryker is much different than expected (80% on paved roads). This, in combination with the added weight of slat armor, has resulted in high stresses to the suspension, wheels and tire assemblies.
8. Since Stryker was fielded in 2003 in Iraq, the operational situation has been dynamic, unpredictable and volatile. Four factors have made it very difficult to obtain complete, reliable, comparable data for the last 4 years. The first factor is the rapidly-evolving adaptive nature of the threat in an asymmetric combat environment. The second factor is that the operational environment for Deployed Stryker vehicles is more severe than anticipated. The third factor is that, in response to the first two factors, configuration changes have precluded a stable baseline. The fourth factor is that in a dangerous combat scenario, recording and reporting data is not a high priority for operational crews.

## Recommendations

1. This research project was inherently difficult due to the lack of availability of complete and accurate data. Future research on this topic should begin with a careful analysis of the specific data that will be necessary to answer a research question, and some assurance that the required data will be available in a usable format.
2. Research should be conducted on programs with a stable product baseline. Meaningful analysis of programs with unstable configuration baselines and incomplete data is very challenging. Specifically, this research project included an evolving weapon system in a volatile and dynamic combat situation.
3. Future research in this area of inquiry should be based on systems that have been fielded for 3 or more years with a relatively stable configuration baseline. Under these conditions, complete and accurate data should be available if proper Systems Engineering principles have been followed (i.e., data management and configuration management).
4. Future research could include a comparison of Stryker cost data with other ground combat systems. This would allow a direct comparison of actual Stryker operating costs with other relevant Army systems (e.g., M113A3, HMMWV, Bradley Fighting Vehicle, or Abrahms Tank).
5. Future research could be conducted on contract type and CDRL requirements to enable better assessments of operating costs.

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## Appendix A – CDRL A003 – Consumption Report

### CDRL A003 – Consumption Report

CDRL A003 is the consumption report (i.e., items removed from the vehicle) and has separate worksheets for **CONUS**, **Deployed**, and **Battle Damaged** vehicles.

Key data utilized in this report include:

- the GDLS part number;
- the National Stock Number (NSN);
- the quantity consumed;
- the quantity failed;
- the failure date;
- the vehicle number;
- the vehicle mileage and hours;
- staff hours to repair;
- a flag to identify warranty items;
- the standard cost of the part; and
- the average unit repair cost.

The Consumption Report was created on September 12, 2006 and has data for the period of Dec. 21, 2004 through August 31, 2006. The data for **CONUS** and **Deployed** was used in this study. The **CONUS** data consisted of 4190 items, while the **Deployed** data consisted of 6994 items.

The **Battle Damage** data was not used in this cost-per-mile analysis because it does not reflect normal operating costs.

It is important to note that the repair cost listed in the report is incomplete (72% of the parts are missing repair cost data). Even when available, the PMO does not use the repair cost listed in CDRL A003 because it has not proven to be reliable.

Instead, CDRL A004 - Repairable Items Repair Cost Summary Report—was used to calculate an average repair cost.

Although CDRL A003 includes warranty items, the PMO wants future costs, so they include the costs of warranty items in their analysis. Only 6% of the parts were identified as warranty items. In this study, all warranty items were included in the cost-per-mile estimates to reflect long-term costs.

The CDRL A003 report appears to be of high quality. For example, all fields are filled in, the data is consistent, and there aren't any noticeable outliers.

**CDRL A003 Data Fields**

<b>Data Elements</b>	<b>Definition</b>	<b>Explanation for Blank Cells</b>
<b>JON</b>	Job Order Number - tracking number created in DMIS.	No blanks.
<b>SubJON</b>	A secondary and more detailed DMIS tracking number	No blanks.
<b>Part Number</b>	Identification number for the part	FSR/soldier failed to complete form properly.
<b>Cage</b>	Code identifying part's origin	Incomplete PMR data.
<b>SMR</b>	Source Maintenance Recoverability Code - identifies a part's repairability and orderability status	Incomplete PMR data.
<b>NSN</b>	NATO Stock Number for the part (if available)	Incomplete PMR data
<b>Nomenclature</b>	Description of the part	FSR/soldier failed to complete form properly.
<b>Std Cost of Part as New</b>	Standard cost of the part as though purchased new	
<b>Failed Qty</b>	Number of parts that failed	FSR/soldier failed to complete form properly.
<b>Order Date</b>	Date the part was ordered for consumption	No blanks on DMIS 4.0 post-Nov 2003 data - any gaps are legacy data issues
<b>Reason for Replacement</b>	Reason the part was ordered for consumption	FSR/soldier failed to complete form properly.
<b>Vehicle Number</b>	Vehicle the part was applied to	FSR/soldier failed to complete form properly.
<b>Miles</b>	Vehicle miles at the time of the failure	FSR/soldier failed to complete form properly.
<b>Hours</b>	Vehicle hours at the time of the failures	FSR/soldier failed to complete form properly.
<b>ManHrs</b>	Total manhours to identify and repair failure	FSR did not complete DMIS data forms.
<b>Warranty</b>	True/False indicator if warranty applies to the replacement of the part	No blanks.
<b>Source</b>	Letter identifier of organization affecting the repairs (I = I-CLS & D = Deprocessing)	No blanks.
<b>Failure Date</b>	Date of the failure	FSR/soldier failed to complete form properly.
<b>Average Unit Repair Cost</b>	Average unit repair cost	
<b>PMR Part Number</b>	RPSTL Part Number	
<b>EC</b>	Essentiality Code	
<b>Failure Code</b>	Complaint Failure Code	



## Appendix B CDRL A004 – Repairable Items Repair Cost Summary Report

### CDRL A004 – Repairable Items Repair Cost Summary Report

CDRL A004 is the Repairable Items Repair Cost Summary Report<sup>16</sup>. Data is listed for **A004 In Process** (i.e., CONUS), **A004 Status Request Closed** (i.e., CONUS), **Deployment in Process**, and **Deployment Status Closed**. Key data utilized in this report include:

- the GDLS part number;
- the National Stock Number (NSN);
- the standard cost of the part;
- a flag to identify warranty items;
- the type of repair cost data (estimate, quote, invoice);
- the total repair price;
- the scrap status (yes or no).

The worksheet **A004 In Process** has 4825 items, **A004 Status Request Closed** has 2801 items, **Deployment in Process** has 1473 items, and **Deployment Status Closed** has 5741 items

The PMO uses the quote (“Q”) and invoice (“I”) data from A004 to get an average repair cost for all parts, then uses the consumption data from A003 to figure out total cost. The estimated average cost per mile (excluding ICLS labor) is computed.

### Scrap Rate

When the scrap data field is “Y”, the part has been scrapped and the standard cost applies to the replacement part. For each part, the scrap rate is determined by dividing the number of scrapped parts by the total number reported.

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<sup>16</sup> The Army uses the word “reparable” while GDLS uses “repairable”.

**Repair Cost**

The field EQI stands for “estimate”, “quote” and “invoice”. When GDLS gets a repair request, they provide an estimate ("E") to the government. The estimate is usually about 60% of the standard cost, so it is of little value in determining the true repair cost. "Q" indicates that the repair cost is a quote from the supplier. When GDLS invoices the government for repair completed, the EQI field is set to "I".

Of the 21681 items with an EQI entry, 22% were “E” (estimate), 75% were “Q” (quote), and only 3% were “I” (invoice). In the cost-per-mile analysis presented in this report, only quoted ("Q") and invoiced ("I") costs were used in estimating *cpm* because the estimates (“E”) were, on average, much higher than quoted or invoiced repairs.

The A004 report appears to be of high quality. For example, all fields are filled in, the data is consistent, and there aren’t any noticeable outliers.

**CDRL A004 – Data Elements**

<b>Data Elements</b>	<b>Definition</b>	<b>Explanation for Blank Cells</b>
<b>RMA Task</b>		RMA not performed
<b>Oracle Service Request #</b>	Unique Oracle tracking number	No Blanks
<b>Vulcan Tracking #</b>	Unique Vulcan tracking number	New records since system conversion, Vulcan no longer tracks these
<b>Part Number</b>	Item number	No Blanks
<b>CAGE</b>	Code identifying part's origin	
<b>NSN</b>	NATO Stock Number for the part (if available)	May not be available
<b>Part Name</b>	Part Description	No Blanks
<b>Qty</b>	Quantity for unique tracking number	No Blanks
<b>Avg. Unit Price of New (USD)</b>	Average price of new in USD	No Blanks
<b>Avg. Extended Price of New (USD)</b>	Average price of new in USD *Note* will be removed on PBL A004	No Blanks
<b>Date Part Received In R &amp; O</b>	Date part arrived in depot for repair	Old Vulcan conversion record
<b>Date Due</b>		
<b>Date Return to ICLS</b>	Date part shipped to ICLS stock for final consumption	Part may not have shipped yet
<b>Vendor Manhours</b>		Not yet available, repair incomplete
<b>Total Parts Cost (Less Labour)</b>	Part cost	Not yet available, repair incomplete
<b>Warranty Yes /No</b>	Warranty, yes or no	No Blanks
<b>Total Turn Around Time from Receipt Date</b>	Turn around time based from date of receipt to date of return	Return ship date not available, cannot perform TAT calculation
<b>Status WIP</b>	Current status in R&O process	No Blanks
<b>EQI</b>	Estimate, Quote, Invoice	No Blanks
<b>Total Repair Price</b>	Total repair cost	Repair not completed, invoicing still outstanding
<b>Serial Number</b>	Item serial number	Part may not be serialized
<b>Scrap Y/N</b>	Scrap, yes or no	No Blanks

## Appendix C – Sustainment KPP

### ***JROC Approved\* Mandatory Sustainment KPP and KSAs***

- **Single KPP:**
  - **Materiel Availability** ( $= \frac{\text{Number of End Items Operational}}{\text{Total Population of End Items}}$ )
- **Mandatory KSAs:**
  - **Materiel Reliability** (MTBF) ( $= \frac{\text{Total Operating Hours}}{\text{Total Number of Failures}}$ )
  - **Ownership Cost** (O&S costs associated w/materiel readiness)
- **For mission success, Combatant Commanders need:**
  - Correct number of operational end items capable of performing the mission when needed
  - Confidence that systems will perform the mission and return home safely without failure
- Ownership Cost provides balance; solutions cannot be availability and reliability “at any cost.”

***\*JROC Approval Letter JROCM 161-06 Signed 17 Aug 06;  
Revised CJCS 3170 will put into Policy***

## **Appendix D – Suitability of Fielded Systems Study – Lessons Learned regarding Stryker NBCRV Reliability Testing**

Richard A. Di Lorenzo, Michael Staniszewski, Michael Croke, and Joe Hubinsky

### **Introduction**

During the course of this research study, the team learned of an interesting reliability testing sequence regarding the Stryker variant known as the Nuclear, Biological, Chemical Reconnaissance Vehicle (NBCRV). This appendix discusses reliability growth and two of the formal reliability-related tests in the NBCRV program, namely Production Qualification Testing (PQT) and Production Verification Testing (PVT). It was compiled by Professor Richard A. Di Lorenzo, of DAU Mid-West - Kettering, Ohio, based largely on NBCRV-related inputs from Michael Staniszewski, Michael Croke, and Joe Hubinsky, reliability engineers from TACOM - Warren, Michigan.

### **The Nature of Reliability Growth, PQT, and PVT**

Reliability growth is defined as “the positive improvement in a reliability parameter over a period of time due to changes in product design or the manufacturing process”. Reliability growth is sometimes called reliability growth testing (RGT), although it is not an actual evaluation, it is a methodology allowing continual improvement during development. One should neither assign pass/fail criteria for a RGT nor allow it to be used as an exit criterion from one phase of acquisition to another because it is not a thorough enough examination of any single design. RGT is most cost-effective during the development phase – when design changes are much less expensive than later. The reliability growth approach is to operate or test a (developmental) item until failure, identify the failure mode, and “fix” or remove the failure mode. Reliability growth testing often ends when there is reasonable confidence that the required reliability may have been achieved.

Production Qualification Testing (PQT) is to assure the latest design is worthy of production. PQT is a real test using a prototype(s). In a PQT there are pass/fail

criteria, such as from the system specification in a contract. PQT may serve as an entrance criterion for the Milestone C decision. For reliability testing purposes, PQT-type testing is covered in MIL-HDBK-781A “Reliability Test Methods, Plans, and Environments for Engineering, Development, Qualification and Production”.

Production Verification Testing or PVT is a real test that uses LRIP assets to assure that the manufacturing process hasn't degraded the reliability. In a PVT there are pass/fail criteria, which may be the same as in PQT. PVT may serve as an entrance criterion to the FRP (full-rate production) decision. PVT-type testing is also covered in MIL-HDBK-781A. PQT and PVT may be considered forms of Reliability Qualification Testing.

Ideally, the sequencing of RGT, PQT, and PVT is in that order. As discussed below, there has been some deviation from that sequencing for Stryker NBCRV.

### **Stryker NBCRV Vehicle Design/Development**

The first eight Stryker variants went through extensive PVT testing prior to being approved for full rate production. The testing conclusively demonstrated that the Stryker chassis met its reliability requirements. The Stryker NBCRV is based on this same chassis.

Since the chassis had already proven to be reliable, the integration of the Nuclear, Biological, and Chemical (NBC) suite was the primary challenge for the contractor. However, the contractor did not take into account the low-speed mission duty cycle of the NBCRV, or its need to maintain air conditioning and overpressure during 100% of the mission. As a result of these operating needs, certain chassis subsystems, such as the hydraulic pumps, were operated at a higher duty factor and failed at a higher rate than on the eight production variants.

### **PQT for Stryker NBCRV**

Since the NBCRV used the same chassis, it was expected to perform as well as the Stryker Production 8 vehicles. The NBCRV was viewed as a developed system and early testing planned for only a very short verification of chassis reliability (NBC

unique and common chassis). NBCRV testing included a Limited User Test (LUT) and an extremely limited Production Qualification Test (PQT). The results showed that the NBCRV fell below its reliability requirements. At the time, the contractor did not have a Systems Engineering Process in place to quickly address failures. Additionally, the contractor did not conduct a Design Failure Mode and Effect Analysis (DFMEA) nor a Process Failure Mode and Effects Analysis (PFMEA) to identify and prioritize potential failure modes.

### **PVT for Stryker NBCRV**

There were minimal reliability-related design changes incorporated into the NBCRV following LUT and PQT testing. MIL-HDBK-189 RGA (Reliability Growth Analysis) methodology was not used to assess the resulting reliability due to “lateness” of correction actions. Instead, the MIL-HDBK-189 “Engineering Analysis with Fix Effectiveness Factors” method was used to assess requirement achievement. Early LRIP vehicles were used to test the NBCRV against the operational requirements in the ORD (Operational Requirements Document) of 1000 MMBSA in the Initial Operational Test (IOT), and its technical requirement of 2000 MMBSA in PVT.

The NBCRV did not meet the reliability requirements in either IOT or PVT. The scheduled 24,000 mile PVT was stopped early so that the contractor could work to identify and implement corrective actions for known failure modes. The result was a delay in the production decision until a clear path for reliability growth work was identified.

### **Future Reliability Growth for Stryker NBCRV**

This additional reliability growth work, referred to in the NBCRV program as “Reliability Test”, will be conducted to confirm the system is on track to meeting its reliability requirements. In effect, failure to pass reliability testing in PVT has driven NBCRV back into reliability growth to “prove” the program is ready to build production vehicles. The contractor is working to implement corrective actions for known failure modes before the Reliability Test begins. Additionally, the contractor

is finalizing a DFMEA/PFMEA to identify unseen failure modes and manufacturing process issues in order to address them before the Reliability Test begins. The Reliability Test will be a 12,000 mile test with the possibility of pauses at 2,000 miles and 7,000 miles to allow the contractor to implement corrective actions for any new failure modes. MIL-HDBK-189 RGA will be applied in the up-coming Reliability Test. The program office will then try to get a DAB Decision to enter Full Rate Production and prove the reliability requirements have been met.

### **Lessons Learned from Stryker NBCRV Reliability Testing**

1. Understand the vehicle's operating cycle and needs before testing begins. Past performance is not always indicative of future success if common components are not run under the exact same set of conditions. Seemingly small changes to vehicle mission may unduly tax some subsystems and decrease reliability.
2. Develop a DFMEA/PFMEA early to identify potential failure modes for the system and implement corrective actions to prevent them from surfacing during test. Eliminating or reducing the potential for a failure mode to surface during testing improves the design of the system.
3. Establish a Systems Engineering Process early in the program to quickly react to failures with corrective actions. Install corrective actions as expeditiously as possible during testing to ensure that corrective actions are "proven out" and the failure has been eliminated. Failure to do so drives up test costs that will come from production dollars.



## Appendix E – Analysis on Vehicle Mileage Reports

Two mileage reports were provided by the PM, but they were incomplete and were not used in the *cpm* analysis. The two files are:

- File 3BDE Mile Hours.xls
- File 3-2 SBCT Mileage 28 Nov.xls

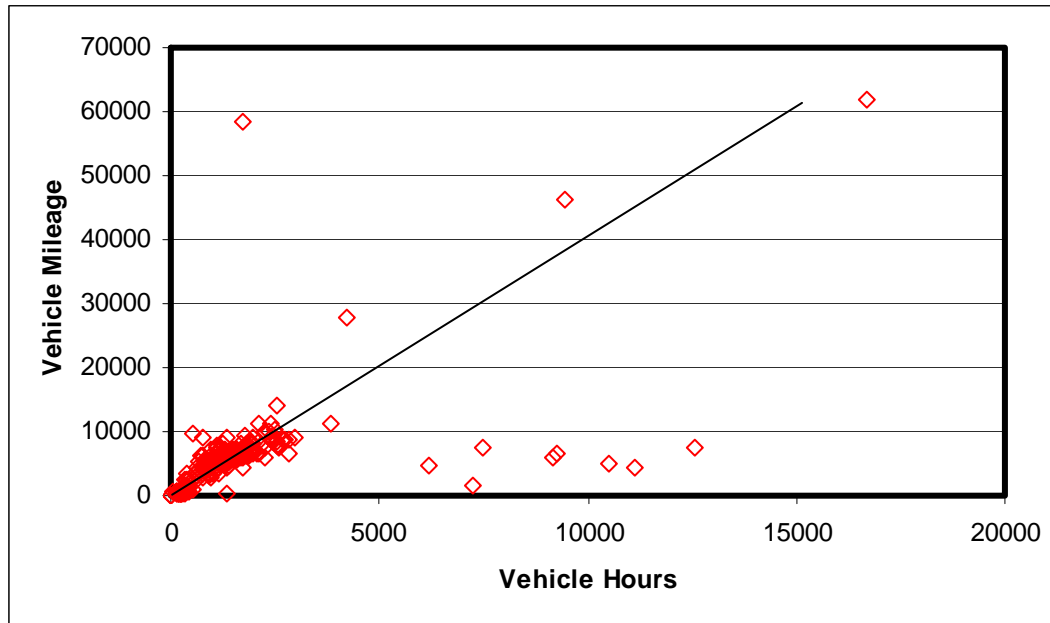
The first file (3BDE Miles Hours.xls) is a mileage report from the late April/May time frame for the 3/2 SBCT. The second file, (3-2 SBCT Mileage 28 Nov.xls) is the mileage reading for the 3/2 vehicles when they were loaded on ships heading to the AOR (it includes data for October and November).

By combining the two reports, it was possible to determine the average miles per day for the vehicles contained in both reports. However, the data was questionable and was not used in the analysis. A description of the data is presented in this appendix.

### 38DE Miles Hours.xls

This report contains mileage and vehicle hours for the 3/2 SBCT. The data was collected in April/May 2006 and contained data for 269 vehicles (7 of the variants). Key data included the variant type, hull number, vehicle mileage and hours.

Figure 10 is a cross-plot of vehicle mileage vs. vehicle hours (i.e., engine hours which are often used for heavy equipment and boats). If the data was consistent, there should be a general linear relationship. There may be a collection of points near the origin for vehicles that have not been operated. A review of the data shows a good linear regression fit to the majority of the data points (Figure 10). However, there are about a dozen outliers. Possible explanations for the outliers include typos in the reported mileage, resetting of the vehicle hours or resetting of the vehicle miles during maintenance or repair. Overall, this data set looks reasonable.



**Figure 10 – Mileage Report #1**

### **3-2 SBCT Mileage 28 Nov.xls**

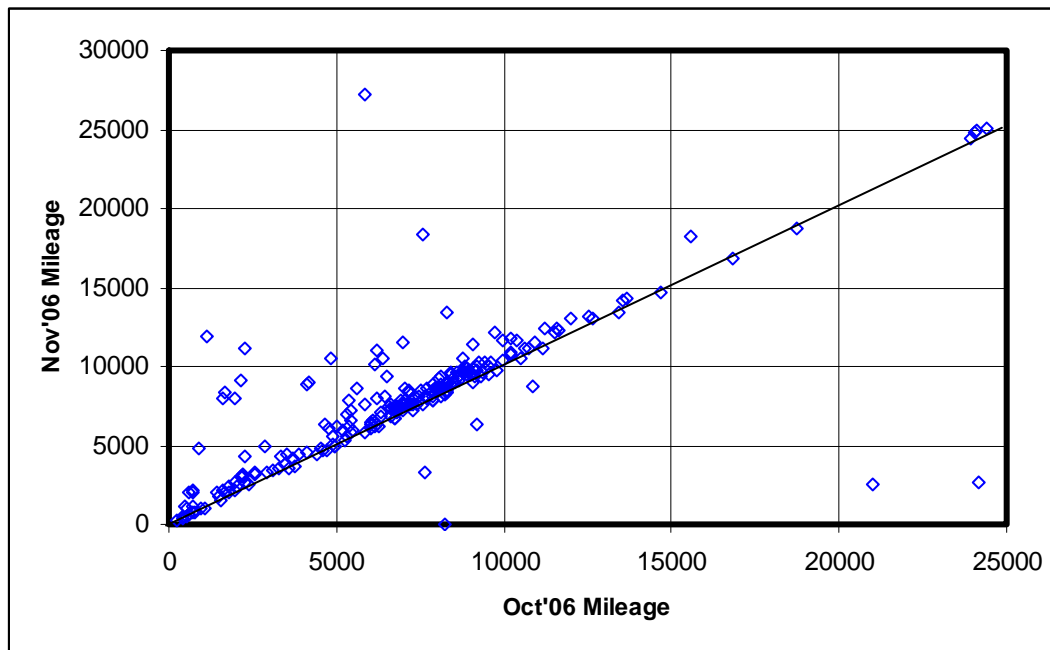
This file is the mileage reading for 3-2 SBCT vehicles when they were loaded onto boats headed to the AOR. The file contained data for 281 vehicles, although there were only 255 Oct. 2006 readings and only 246 Nov. 2006 readings.

Figure 11 is a cross-plot of the November mileage reported and the October mileage. If the data was consistent, there should probably be points on the line that passes from the origin to (25000, 25000). Points on the line will be vehicles that have not been operated during the October-November time period.

Points above the line will indicate that the vehicle has been utilized during the reporting period. However, the points should not be thousands of miles above the line. For example, one vehicle “apparently” traveled 8000 miles in one month; that equates to about 267 miles per day. At an average speed of 30 miles/hr, the vehicle would have had to have been driven nearly 9 hrs/day for 30 days straight. Outliers above the line are probably due to bad mileage readings.

Points below the line are vehicles with a November mileage reading less than the October mileage reading (i.e., negative mileages for the month). These points also indicate a problem with the data.

Overall, the data is questionable for use in determining cost per mile.



**Figure 11 – Mileage Report #2**

The two mileage reports were analyzed together to determine the mileage from April/May to October and/or November 2006. Figure 12 plots the number of vehicles that have an average daily mileage reading between the values on the y-axis. Note that the y-values are not linear (i.e., some divisions are 10 miles/day, while others are 100 or more per day). Of the 226 vehicles represented in the figure, there are 7 negative values and 20 values greater than 100 miles/day. Because of the negative values (obvious errors), and the large number of vehicles that show hundreds of miles per day (for 6 months straight), the mileage data from these reports were not used in this research project. Instead, mileage data was determined from CDRL A003 using the procedure presented in Chapter 4.

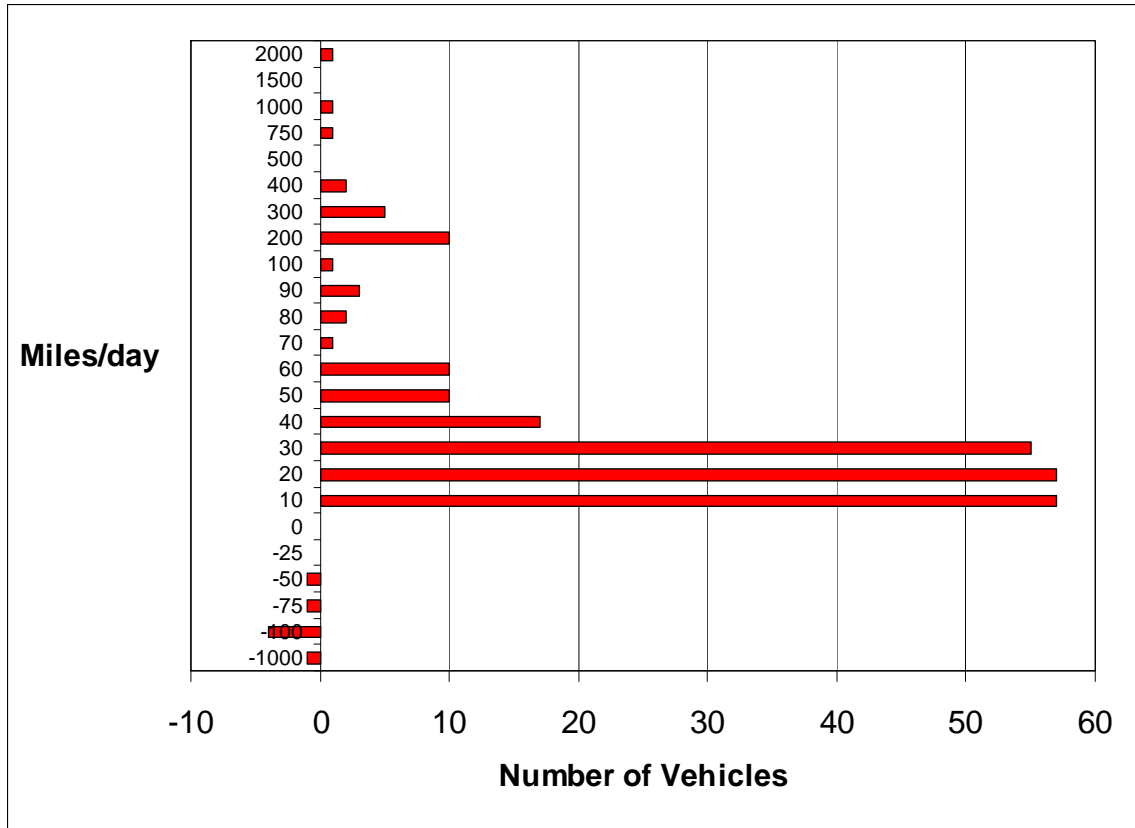


Figure 12 – Mileage Report #3

## List of Acronyms

AEC .....	U.S. Army Evaluation Center
AOR .....	Area of Responsibility
ATEC .....	U.S. Army Test & Evaluation Command
BLRIP .....	Beyond Low-rate Initial Production
CDRL .....	Contract Data Requirements List
CONUS .....	Continental United States
CPFF .....	Cost Plus Fixed fee
<i>cpm</i> .....	Cost per mile
DAU .....	Defense Acquisition University
DFMEA .....	Design Failure Mode and Effect Analysis
DOT&E .....	Director of Operational Test & Evaluation
DSB .....	Defense Science Board
DT&E .....	Developmental test & Evaluation
GAO .....	General Accountability Office
GDLS .....	General Dynamics Land Systems
HMMWV .....	High-Mobility Multipurpose Wheeled Vehicle
ICLS .....	Interim Contractor Logistics Support
IDA .....	institute for Defense Analysis
IED .....	Improvised Explosive Device
IETM .....	Interactive Electronic Technical Manual
IOT&E .....	Initial Operational Test & Evaluation
JROC .....	Joint Requirements Oversight Council
KPP .....	Key Performance Parameter
LMI .....	Logistics Management Institute
LUT .....	Limited User Test
PQT .....	Production Qualification Test
NSN .....	National Stock number
OMS/MP .....	Operational Mode Summary/Mission Profile
OPTEMPO .....	Operational Tempo

ORR.....Operational Readiness Rate  
 OSD .....Office of the Secretary of Defense  
 OSMIS .....Operating and Support Management Information System  
 O&S .....Operation and Support  
 PBL .....Performance Based Logistics  
 PFMEA .....Process Failure Mode and Effects Analysis  
 psi .....Pounds Per Square Inch  
 RAM.....Reliability, availability and maintainability  
 RGT .....Reliability growth testing  
 RPG .....Rocket Propelled Grenade  
 SBCT .....Stryker Brigade Combat Team  
 TLCSM.....Total Life Cycle Systems Management  
 USD(AT&L)..Undersecretary of Defense for Acquisition, Technology and Logistics